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THE CAPILLARY DISTRIBUTION OF MOISTURE IN SOIL COLUMNS OF SMALL CROSS SECTION

By W. W. McLaughlin, *Senior Irrigation Engineer, Bureau of Public Roads.*

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In many of the irrigated sections of the west permanent ground water is present at or near the ground surface, frequently so near as to necessitate drainage before the lands can be cultivated successfully. In other instances the ground water is a factor in supplying moisture to plants or in alkali distribution.

In either case it is essential to know how much water will be raised in the soil by capillarity to various heights from the ground water level, i. e., the vertical distribution of the capillary water. In the case of drainage this information is necessary in order to determine how completely the soil may be dried out by under drains or open ditches when the ground water is lowered to a definite level. The extent of this drying out will in many cases influence the depth at which the drains will be placed.

If, on the other hand, the field is to be irrigated and ground water known to be present, is counted upon to supply a part of the moisture required by the plants, it is necessary to know the extent to which the supply will be drawn from the ground water, which again implies the necessity of some knowledge of the distribution of the water raised by capillary action.

The rate of capillary movement was determined for several soil types in a series of investigations conducted by the author at Riverside, Calif.[1] The rate of movement is an important consideration to the irrigator, especially the rate of movement in a vertical direction. But the amount moved is of still greater importance. In the earlier experiments a difference was found in the amount of water required per inch of rise of the capillary moisture. It was found also that this

[1] Bulletin No. 835, United States Department of Agriculture.

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difference was not uniform, and assuming the column of soil to be uniform, this difference could be explained only in one or both of two ways: Either the distribution of moisture did not vary uniformly from one end of the soil column to the other, or the moisture moved upward, not gradually, but in waves. There is reason to believe both of these conditions exist; but the purpose here is to consider only the distribution of the moisture, the result and not the cause.

The experiments planned to throw light on the distribution of the moisture were conducted at intervals over a period of six years. They differed from the earlier experiments in the use of columns of small cross section instead of comparatively large columns. The change to the smaller columns was not only a matter of convenience, but of necessity to insure accurate soil sampling. It is undoubtedly true that the laws governing capillary distribution of soil moisture as determined in small columns would also govern in the field, hence the size of the column is not material.

THE PRINCIPAL RESULTS OF THE EXPERIMENTS.

The experiments disclosed a number of very interesting and important facts with regard to the distribution of soil moisture in the soils tested.

The maximum percentage was found, not immediately above the water surface, but at an appreciable distance above it.

The capillary moisture was not distributed at a rate uniformly decreasing with the distance above the water table, but irregularly. In most cases the maximum percentage of moisture to be found in the wetted area of the soil above the water table was several inches above the surface of the water. The average percentage of moisture contained in this wetted area above the water table was found at about three-fifths of the height in most cases. In a majority of the soils used in these experiments the lower half of the wetted area above the water table contained too much moisture for the best growth of most plants. These tests show that in the presence of a water table, plant roots need not go to the water table itself for moisture.

In a loam or heavier soil, a shallow drain, say 2 or 3 feet below the surface, either open or closed, would in the presence of a water table remove but little water from the soil above the drain. In case of under drainage, where the water table remains at the level of the drains, there is a large amount of moisture held by the soil above the drains not subject to drainage.

The distribution of soil moisture in a horizontal direction in the field depends very largely upon the possibility of vertical movement either upward or downward. If there are rather impervious strata both above and below a stratum of soils such as those used in these tests, then the lateral distribution will be somewhat uniform over the entire wetted area, with a tendency to decrease gradually with distance from the source of water.

If these semi-impervious or impervious strata incline downward at 15 degrees or more from the horizontal, then the intervening stratum will have a moisture distribution differing from either the vertical or

horizontal. The percentage of moisture in such a case will decrease somewhat irregularly with distance from the source of water. If this inclined stratum encounters an impervious stratum so as to retard or stop entirely the capillary movement of moisture downward, the moisture will then accumulate and ultimately cause saturation. This saturated area will in time extend back up to near the original source of moisture. In alluvial soils such conditions are often found and water-logging may result in this way.

The capillary distribution of moisture in the presence of a water table is of far more importance in irrigation and drainage than is usually recognized.

RESULTS OF PREVIOUS EXPERIMENTS.

It has been mentioned that the results of some of the experiments at Riverside indicated an uneven distribution of moisture throughout the vertical soil columns. The first two determinations made for the distribution of moisture in vertical soil columns at Riverside were for Riverside and Whittier soils. These columns were respectively 7 by 7 inches and 8 by 8 inches in cross section.

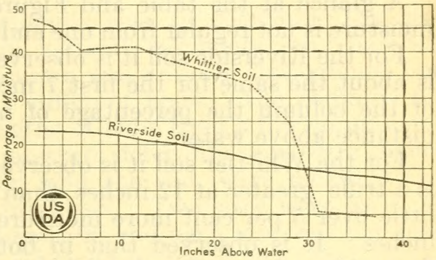

FIG. 1.—Distribution of moisture in large vertical columns.

The moisture in these columns was determined at various heights throughout the columns, the samples being taken with a soil auger. The percentages of moisture found at various heights above the water are plotted in Figure 1.

EXPERIMENTS WITH SOIL COLUMNS OF SMALL CROSS SECTIONS.

In taking samples with a soil auger from soil that is near capillary saturation one can never be certain that an accurate sample is obtained. For this reason the results from these two large columns were not relied upon as correctly representing the moisture conditions that existed. They indicated, however, that the distribution of moisture in vertical soil columns might not be uniform as was commonly supposed.

Table 1 gives the results of moisture determinations for these two columns. The percentages of moisture are calculated upon a dry-soil basis. The first column gives the distance above the surface of the water at which the samples were taken. Opposite these distances are found the corresponding percentages of moisture for the two soils.

TABLE 1.—*Percentages of moisture in soil columns at different distances above water, as obtained from the Riverside experiments.*

Distance above water.	Riverside soil.	Whittier soil.	Distance above water.	Riverside soil.	Whittier soil.
Inches.	*Per cent.*	*Per cent.*	*Inches.*	*Per cent.*	*Per cent.*
1	22.85	46.74	19	18.60	.....
3	.....	45.33	21	.....	34.75
4	22.84	.....	22	17.73	.....
6	.....	40.25	24	.....	32.82
7	22.45	.....	25	16.33	.....
9	.....	40.70	28	15.00	24.59
10	21.85	.....	31	14.36	5.59
12	.....	40.84	34	13.18	.....
13	20.59	.....	37	13.05	4.60
15	.....	38.11	40	12.12	.....
16	20.05	.....	43	11.21	.....
18	.....	36.49			

A glance at the table and Figure 1 shows that the distribution of moisture is not regular from one end of the column to the other.

For the Riverside soil it is observed that the percentage of moisture is about the same for the first 7 inches. From there to near the top of the column the percentage of moisture decreases regularly with distance above water.

For the Whittier soil it is observed that the percentage of moisture is a trifle greater at 12 inches than at 6 inches above water, while a little over 5 per cent more moisture was found at 3 inches than at 6 inches. It is observed that in both columns the moisture content decreases rather uniformly with difference in height above the lower 12 to 16 inches. The results obtained from these two columns, while not in any way considered conclusive, due to methods of sampling, created a doubt as to the uniformity of moisture distribution in vertical soil columns having the lower end in water. It was to clear up this doubt and eliminate other apparent irregularities arising in the Riverside work that the other experiments recorded in this bulletin were undertaken.

SOIL USED.

The soils used in the experiments were:

Decomposed granite (sandy) from Riverside, Calif.
Heavy black clay loam from the coastal plain near Whittier, Calif.
Idaho sandy loam.
Idaho lava ash loam.
Medium clay loam from Santa Clara Valley, Calif.
Medium loam from Cache Valley, Utah.

Each of these soils was taken from the top 8 inches of the field, and none contained any artificial fertilizer. Each sample was mixed thoroughly, screened through a 10-mesh screen and remixed into a uniform mass.

WILTING PERCENTAGES.

For the sake of comparison and reference the wilting point and moisture equivalent of the soils used were ascertained, and these factors, as determined by the Briggs-Shantz method by C. A. Jensen of the Bureau of Plant Industry, are recorded in Table 2.

TABLE 2.—*Wilting points and moisture equivalents of the soils used.*

Soil.	Wilting point.	Moisture equivalent.
	Per cent.	*Per cent.*
Riverside soil	4.3	7.9
Whittier soil	20.8	38.3
Idaho (sandy) soil	2.5	4.7
Idaho (lava ash) soil	9.9	18.3
Santa Clara soil	11.30	20.80
Utah (medium loam) soil	12.05	22.23

A considerable difference in the characteristics of the soils is denoted by the two factors, and it is worthy of note that the Santa Clara and Cache Valley soils, the characteristics of which are similar according to these factors, are greatly different in appearance.

PLAN OF EXPERIMENTS.

The plan of the present experiments was to determine the distribution of capillary moisture in vertical, horizontal, and inclined soil columns. The soil of each column was uniform throughout, but different soil types were used for different tests. The columns remained in position for various lengths of time from a few minutes to several weeks before samples for moisture determinations were taken.

The tubes, or containers which held the soil, were nickel-plated brass tubing such as is used by plumbers. Two sizes were used, 1¼ and 1½ inches, respectively, in diameter, and each size was cut into 1-inch lengths with milled ends. Thus when one of the 1-inch pieces was placed upon another there was a snug, dirt-proof, but not air-tight, joint between them. The bottom section of each tube had soldered over the lower end a piece of fine-mesh brass wire gauze to hold the soil in the tube when the lower end of the column was submerged in a vessel of water. In some cases the joints between the 1-inch sections were sealed by wrapping with friction tape; in others they were left unsealed. Two strips of wood nailed together in the shape of a small trough, to which the sections of tubing were secured by friction tape, acted as a support or stiffener for the column. When the joints of the tube were not sealed with the friction tape the tubing was held to the wooden angle by a second angle made of heavy galvanized iron.

FILLING SOIL TUBES.

Several methods of compacting the soil into the tubes were tried with a view of eliminating, if possible, any error caused by nonuniform packing. In some tubes sufficient soil was added at a time to fill three of the 1-inch sections. The whole tube was then lifted, while in a vertical position, about 5 inches from the floor and allowed to drop to the floor. This lifting and dropping was repeated three times for each layer of soil added. Thus the tube was filled layer by layer to the desired height. In several instances two tubes were filled with the same soil in this way and one of them turned end for end before being placed with one end in the vessel of water. These two tubes, one having the end that was filled first in the water and the other having the end filled last in the water, should, when compared by analysis, indicate any lack of uniformity due to packing.

A second set of tubes was filled by dropping the soil into them from a uniform height, the drop remaining the same for each 2-inch section filled. This was the method employed by the late Dr. R. H. Loughridge. In this case also two tubes were filled with the same soil and one of them was inverted before being placed in water.

A third set was filled by packing a uniform weight of soil into each 1-inch section of the tube.

A fourth method employed was that of filling the tubes in 2-inch layers and tamping each layer with a wooden rod slightly smaller in diameter than the tubing.

The dropping of a weighted tamping rod a definite distance upon each 1-inch layer also was tried.

As it was not the purpose of these experiments to determine the best method of packing tubes, it is sufficient to say that an analysis of the data did not indicate that the methods of packing were in any way responsible for the distribution of moisture found. The data did indicate, however, that the method of packing influenced to some extent the total quantity of water held in the tube.

VENTILATION OF TUBES.

In the first experiments each joint between the 1-inch sections was made air-tight by wrapping with friction tape. This made each soil column practically air-tight from one end to the other. Then, if air-trapping did occur in the soil column used by other experimenters it would also occur in these tubes. In order to provide for a rather free air circulation within the soil column, some of the tubes were left with the joints between sections unwrapped. Thus the air could enter or escape from the soil at each inch in height. A third set of tubes having a slot one-fourth inch wide cut from one end to the other was made for two of the soils. This slot was covered with a very fine wire gauze.

After a tube had been filled with soil it was placed on end in a vessel of water and the water maintained at a uniform elevation covering the bottom half inch of the soil column. The tubes were allowed to stand in position for various lengths of time before sampling was undertaken.

SAMPLING.

Various methods were employed in breaking a soil column into its 1-inch sections at the termination of an experiment. In some cases the tube was removed from the water, the bottom section discarded, and the remainder of the tube separated into sections inch by inch. As fast as a 1-inch section was removed the soil from that section was placed in a tared glass bottle and the top screwed on. In other instances the tube was left standing in water and the column was dismantled inch by inch, commencing at the top. In other cases the tube was removed from the water, laid on its side, the tape joints were cut quickly, and the tube was broken up into 1-inch sections as rapidly as possible and before any of the samples were placed in the bottles. Some of the tubes were allowed to stand in a vertical position for 24 hours after having been removed from the water before sampling.

In all cases, unless specially noted, each inch in height or each 1-inch section constituted a separate sample.

DETERMINING MOISTURE CONTENT.

As soon as a set of samples had been taken and placed in the tared bottles they were weighed, placed in a water-jacketed oven, and kept at the temperature of boiling water until constant weight was obtained. They were then weighed again and the loss of water was determined. All moisture percentages were calculated on the basis of the dry-soil weight.

IDAHO SANDY SOIL.

The first set of experiments was made upon the sandy soil from Idaho. The set consisted of four tubes, each tube being treated differently in one way or another.

Tube No. 1 was packed in 2-inch layers. Each layer was packed by lifting the tube 4 inches and dropping it to the floor. This dropping and lifting was repeated three times for each 2-inch layer. After packing, the tube was allowed to stand vertically with the lower end in the water for 30 days. It was then taken down and immediately sampled, commencing with the bottom inch.

Tube No. 2 was packed in the same way as tube No. 1, and was allowed to stand vertically with the lower end in the water for 35 days. The tube was then removed from the water and allowed to stand vertically 24 hours out of the water before sampling. It was then sampled in the same way as tube No. 1.

Tube No. 3 was packed by tamping each 2-inch layer with a weighted tamping rod. The rod was lifted and dropped three times for each layer. The tube was allowed to stand vertically with the lower end in the water for a period of 40 days, and was then sampled without removing the lower end from the water. Commencing with the top inch of moistened soil the tube was taken down inch by inch as rapidly as possible.

Tube No. 4 was packed in the same manner as tube No. 1, and turned end for end before being placed in position. Thus the top of the tube as it was packed became the lower end when placed in position. This tube stood 42 days and was then sampled without removing the lower end from the water, the same as tube No. 3.

All four tubes had their joints covered with friction tape.

In sampling these and all other tubes used in the experiments the bottom 1-inch section which stood with its lower end submerged half an inch below the water surface was discarded. Thus the bottom of the first 1-inch section tested was half an inch above the water surface.

Table 3 gives the percentage of moisture in each inch of the four tubes. The first column gives the distance of the sample above the water or, stated accurately, the order of the section in the column from the water surface, omitting the first, or partly submerged section. Thus, 1 represents the soil of the first unsubmerged section; 2 represents the soil of the second unsubmerged section, etc. The second, third, fourth, and fifth columns give the percentages of moisture as determined for tubes Nos. 1, 2, 3, and 4.

TABLE 3.—*Distribution of capillary moisture in vertical soil columns of Idaho sandy soil, by percentage.*

Distance above water.	Tube No. 1.	Tube No. 2.	Tube No. 3.	Tube No. 4.	Distance above water.	Tube No. 1.	Tube No. 2.	Tube No. 3.	Tube No. 4.
Inches.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Inches.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	20.85	22.17	....	....	15	10.01	9.68	10.98	9.89
2	20.80	21.94	23.06	21.02	16	9.61	9.52	10.58	10.03
3	21.73	23.81	22.80	21.27	17	8.61	8.55	9.27	9.16
4	24.98	23.34	22.80	24.10	18	7.97	7.99	8.98	8.48
5	24.67	24.24	25.83	25.89	19	7.41	7.64	8.51	7.71
6	22.83	21.20	24.86	21.54	20	7.05	7.30	8.16	7.14
7	19.72	18.22	20.69	19.02	21	6.27	6.54	7.69	6.86
8	18.19	16.49	18.53	17.02	22	5.74	5.89	7.34	6.15
9	16.07	15.00	17.23	15.55	23	3.80	4.72	6.36	5.64
10	14.45	13.45	15.78	13.98	24	....	....	5.73	4.60
11	13.05	13.07	14.58	12.73	25	....	....	4.50	....
12	12.00	11.58	12.56	12.61					
13	11.26	10.43	12.22	11.71	Average	13.80	13.59	13.78	13.17
14	10.40	9.81	11.52	10.70					

Figure 2 shows in diagrammatic form the data given in Table 3 for tubes 1, 2, 3, and 4. Referring to the curves shown in the figure

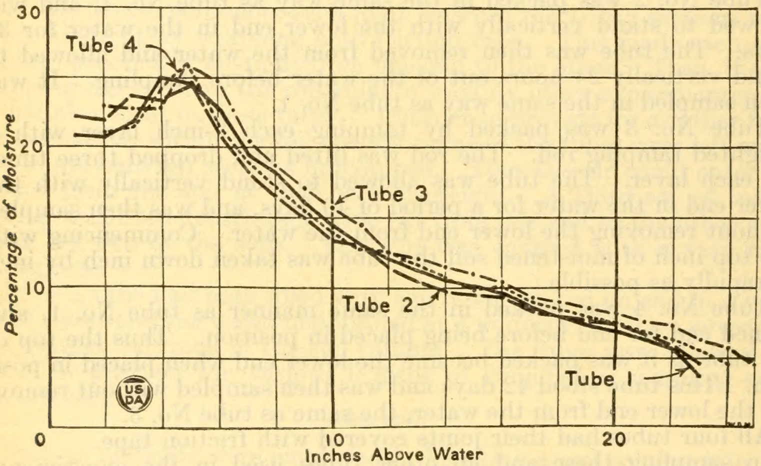

FIG. 2.—Distribution of moisture in vertical columns, Idaho sandy soil.

the first thing that strikes the eye is the irregularity of the transverse lines and the high point occurring in the lines—a short, almost horizontal stretch of the line, then a rather abrupt rise, a rather short rounding apex, and a rapid descent. This descent becomes less and less abrupt and about half-way across it becomes much more gradual and uniform. The apex of each profile line is observed to be on, or a short distance to the left of, the vertical 5-inch line. The striking feature of these curves is that the highest point in these lines, indicating the greatest percentage of moisture, is found, not at the lower end of the tube, but at an appreciable distance above.

Referring now to Table 3, it is found that the moisture in tubes Nos. 1 and 2 reached a height of 23 inches; in tube No. 3, a height of 25 inches, and in tube No. 4, a height of 24 inches. The first two tubes stood 30 and 35 days, and the last two 40 and 42 days. This indicates that the moisture was moving upwards very slowly, as

tube No. 4 stood 12 days longer than tube No. 1, and the moisture in the former had reached not more than 1 inch higher than in the latter.

Without analyzing in detail all the figures representing the percentages of moisture, it is found that in all of the tubes the maximum percentage of moisture is near the fifth inch, or about one-fifth the height to which the moisture had reached, and is appreciably greater at this point than in the first or second inch. It is also found that the percentage of moisture in the inch next to the top inch is between one-fourth and one-fifth of the maximum.

Although treated in different ways and standing different lengths of time the four tubes show very uniform average percentages of moisture. Almost the same average is found in the first 6 inches of the four tubes with a minimum of 22.64 per cent in tube No. 1 and 23.87 per cent in tube No. 3. The second 6 inches in each tube shows the greatest variation in average moisture percentage.

The average percentage of moisture contained in the whole tube is found in tube No. 1 between the tenth and the eleventh inch; in tube No. 2 at about the tenth inch; in tube No. 3 between the eleventh and twelfth inch, and in tube No. 4 between the tenth and eleventh inch. In all of these tubes the average percentage of moisture is found at a little less than half the height of the wetted part of the column.

There is nothing in the table to indicate that the height at which the maximum percentage of moisture occurs is influenced either by the length of time, between 30 and 40 days, that the tubes were left standing, or by the methods of packing. These four tubes, showing as they do that the greatest percentage of moisture is about 5 inches above the water, afford a reasonable basis for saying that such a condition would be found in other tubes, filled with the same or a similar soil. The four tubes do not represent all the tests made with this soil in vertical columns, but are representative of 8 or 10. In no tube of all the experiments with this soil was the maximum percentage of moisture found below the third inch. It was found that in tube No. 1, 71 per cent of all the moisture in the whole tube was in the bottom half. In tubes Nos. 2 and 3, there was found in the bottom half 70 per cent of all the moisture in the tubes.

IDAHO LAVA ASH SOIL.

The second set of experiments was conducted with Idaho lava ash soil. This soil differs widely from the Idaho sandy soil. It is a fine-grained soil, has a different base, and a much greater capillary power. It is also a soil that cracks in drying after saturation and is quite sticky when wet. The set of experiments consisted of four tubes, each of which was treated differently, either in packing or in method of sampling.

Tube No. 5 was packed in 2-inch layers by lifting and dropping the whole tube for each layer, following the method used in packing tube No. 1. The tube was allowed to stand in a vertical position for 30 days. It was then taken down and sampled immediately.

Tube No. 6 was packed by dropping the soil a definite distance for each 2-inch layer. The tube was allowed to stand 35 days. It was then removed from the water and allowed to stand 24 hours before sampling.

Tube No. 7 was packed by tamping each 2-inch layer with a weighted tamping rod. The tube was allowed to stand 46 days, and was sampled immediately, commencing with the bottom inch.

Tube No. 8 was packed in the same manner as tube No. 5 and was allowed to stand just long enough for the moisture to appear at the top of the ninth inch. The tube was then removed from the water and sampled immediately.

Table 4 gives the moisture percentages as determined for each 1-inch section of the tubes. The arrangement of the table is the same as that of Table 3.

TABLE 4.—*Distribution of capillary moisture in vertical soil columns of Idaho lava ash soil, by percentages.*

Distance above water.	Tube No. 5.	Tube No. 6.	Tube No. 7.	Tube No. 8.	Distance above water.	Tube No. 5.	Tube No. 6.	Tube No. 7.	Tube No. 8.
Inches.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Inches.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	25.02	26.24	28.82	31.60	35	25.08	24.30	26.33	....
2	25.28	26.41	29.33	31.76	36	24.91	23.62	26.30	....
3	25.80	27.58	29.17	31.68	37	24.44	23.17	25.63	....
4	27.63	28.50	28.89	31.43	38	24.14	22.43	25.35	....
5	28.45	29.36	29.09	30.82	39	24.28	24.65	25.27	....
6	28.58	29.27	29.88	31.01	40	23.88	23.09	24.81	....
7	28.39	30.28	30.12	30.52	41	23.25	24.15	24.60	....
8	27.54	29.73	30.60	29.90	42	22.71	23.79	24.65	....
9	29.41	29.73	30.97	28.96	43	22.30	23.18	24.24	....
10	....	31.56	30.75	....	44	21.98	22.80	22.93	....
11	32.68	29.08	32.28	....	45	21.81	22.41	23.28	....
12	33.30	30.57	32.06	....	46	21.70	22.23	22.93	....
13	32.21	33.30	32.26	....	47	20.68	22.03	22.61	....
14	33.13	34.13	33.12	....	48	20.41	20.90	22.28	....
15	32.35	32.98	34.74	....	49	19.70	20.69	22.42	....
16	32.40	29.49	33.27	....	50	19.46	20.61	22.19	....
17	29.22	27.30	33.23	....	51	19.52	20.23	22.11	....
18	31.88	27.63	32.52	....	52	18.69	19.88	21.30	....
19	32.12	30.05	32.30	....	53	17.98	19.47	21.47	....
20	31.40	31.06	32.16	....	54	17.47	19.16	21.12	....
21	31.18	30.79	31.62	....	55	16.58	18.68	20.60	....
22	29.68	27.01	31.71	....	56	15.31	18.03	20.33	....
23	30.17	23.77	31.49	....	57	13.59	17.25	19.45	....
24	28.98	26.73	30.97	....	58	....	16.72	18.80	....
25	27.90	26.00	31.37	....	59	....	16.25	18.34	....
26	28.16	27.04	31.78	....	60	....	14.75	17.43	....
27	27.47	27.45	29.99	....	61	....	13.68	16.84	....
28	27.90	27.13	28.52	....	62	....	10.87	16.33	....
29	27.69	25.63	28.39	....	63	....	....	15.63	....
30	26.98	23.69	27.88	....	64	....	....	14.62	....
31	26.55	25.06	28.32	....	65	....	....	13.48	....
32	26.12	23.87	27.10	....	66	....	....	10.13	....
33	25.90	24.55	26.55	....					
34	25.32	24.67	26.72	....	Average.	25.65	24.62	25.93	30.85

Figure 3 gives the information of Table 4 graphically. A glance at the curves for tubes Nos. 5, 6, and 7 shows the transverse lines in the form of irregular curves with the highest point nearer the one

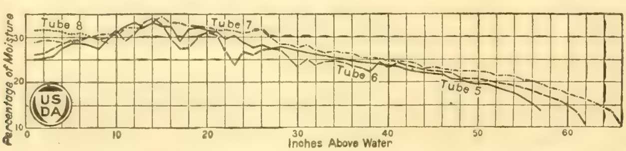

FIG. 3.—Distribution of moisture in vertical columns, Idaho lava ash soil.

end of the line than the other. The curves for tubes Nos. 5 and 6 are quite broken, and this is especially true of the curve for tube No. 6. The curve of tube No. 7 is much more regular. It will be noticed that the highest point in the three curved lines is a considerable dis-

tance from the left or bottom end, and occurs from the twelfth to the fifteenth inch. It is also seen that the highest point in these curves, representing the maximum percentage of moisture, is about the same in all three tubes. The curves show that in tube No. 5 there is more moisture in each inch from the second to the thirty-fifth inclusive, than in the bottom or first inch. In tube No. 7, there is more moisture at each inch from the second to be twenty-seventh inclusive than in the first inch; in tube No. 6, there is more moisture at each inch except two from the second to the twenty-eighth inclusive than in the bottom inch.

In all three curves there is more than one "node" or apex. However, with the exception of the highest one the others are not very pronounced. If a straight line be drawn from the highest apex of the curves for tubes Nos. 6 and 7 to the left end of the line it will be found to represent about the average of the percentages represented in that part of the curved line. If from this same apex a straight line be drawn to within 3 or 4 inches of the right end of the curve, it will correspond very closely to the average percentage of moisture represented by this line.

Table 4 shows a considerable variation in the percentages of moisture found in the bottom few inches of tubes Nos. 5, 6, and 7. In tube No. 5 the maximum percentage of moisture is found at the twelfth inch, in tube No. 6 at the fourteenth inch, and in tube No. 7 at the fifteenth inch.

In all three tubes there are high and low apexes or peaks in the bottom half of the tubes. The average percentage of moisture in the lower part of each tube is, for tube No. 5, 29.03 per cent in the first 14 inches; for tube No. 6, 29.93 per cent in the first 15 inches; and for tube No. 7, 30.96 per cent in the first 16 inches. In view of the different treatment the tubes received, the close agreement of these percentages is remarkable. Tubes Nos. 5 and 7 agree very closely in the remainder of the columns, but tube No. 6 has a slightly lower moisture content than either in the second quarter. In tube No. 5, the average percentage of moisture found between the fourteenth and twenty-eighth inches is 4 per cent higher than the average percentage found from the first to the fourteenth inch. In tube No. 6 the average percentage of moisture in the first 15 inches is 29.93 and in the second 15 inches 27.38 per cent. The average percentage of moisture found in these tubes at the end of the experiment was 25.65 per cent, 24.62 per cent, and 25.93 per cent, respectively. Tubes Nos. 5 and 7 agree very closely in these averages.

From the table it is found that tube No. 5 contained the average percentage of moisture at about the thirty-third inch, or a little more than half way up the tube. Tube No. 6 contained the average percentage of moisture at about the thirty-fourth inch, and tube No. 7 about the thirty-sixth inch. Thus in all these tubes the average percentage of moisture occurs just above the middle of the tube, and in this respect they differ from the first four tubes filled with the Idaho sandy soil. The maximum percentage of moisture found in tube No. 5 is about one-third greater than the percentage in the first or bottom inch. The maximum in tube No. 6 is 34.13 per cent while in the first inch the moisture content is only 26.24 per cent. In tube No. 7 the maximum is 34.74 per cent while the first inch contains 28.82 per cent of moisture.

WHITTIER AND RIVERSIDE SOILS.

The third set of experiments consisted of four tubes, two filled with Whittier soil and two with Riverside soil.

Tube No. 9 was filled with Whittier soil packed in 2-inch layers and compacted by lifting and dropping in the same way as tube No. 1. This tube was allowed to stand 29 days and was then sampled immediately.

Tube No. 10 was filled with Whittier soil and packed in 2-inch layers. Each layer was made firm with a weighted tamping rod. The tube was allowed to stand 18 days and was then sampled immediately.

Tube No. 11 was filled with Riverside soil. The tube was packed in 2-inch layers and made firm by dropping to the floor in the same manner as tube No. 1. This tube was allowed to stand 35 days and was then sampled immediately.

Tube No. 12 was filled with Riverside soil. The tube was packed in 2-inch layers and made firm with a weighted tamping rod. The tube stood but a few minutes—just long enough for the moisture to reach the top of the ninth inch—and was then sampled immediately.

The moisture determination for these four tubes are given in Table 5.

TABLE 5.—*Distribution of capillary moisture in vertical soil columns of Whittier and Riverside soils, by percentage.*

Distance above water.	Tube No. 9.	Tube No. 10.	Tube No. 11.	Tube No. 12.	Distance above water.	Tube No. 9.	Tube No. 10.	Tube No. 11.	Tube No. 12.
Inches.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Inches.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1		48.61	23.55	19.60	30			18.45	
2	55.77	49.72	23.83	20.99	31			18.07	
3	56.21	52.58	24.56	21.69	32			17.96	
4	58.87	52.80	25.20	22.27	33			17.28	
5	57.14	53.80	26.24	22.17	34			16.63	
6	53.69	52.20	25.89	21.04	35			16.38	
7	54.91	49.90	26.59	19.15	36			15.95	
8	52.11	48.10	26.40	18.81	37			15.66	
9	50.24	45.68	27.36	17.64	38			16.00	
10	49.22	44.20	26.85		39			15.28	
11	47.37	43.55	26.70		40			14.58	
12	47.26	40.50	26.75		41			14.39	
13	46.07	41.07	26.64		42			14.03	
14	46.07	39.25	26.93		43			13.71	
15	45.18	38.05	26.72		44			13.78	
16	44.52	37.15	25.28		45			12.84	
17	43.30	35.03	24.90		46			12.19	
18	42.89	32.90	24.01		47			12.00	
19	41.63	32.82	23.25		48			11.07	
20	39.40	30.85	22.49		49			10.27	
21	38.98		21.70		50			10.02	
22	38.22		21.66		51			9.53	
23	38.46		20.91		52			8.97	
24	36.61		21.04		53			8.29	
25	35.41		20.60		54			7.00	
26	33.60		19.25		55			4.92	
27	30.89		19.68						
28	22.18		19.00		Average	44.67	43.44	18.87	20.37
29			18.70						

Figure 4 shows graphically the data given in Table 5. The curves for tubes Nos. 9 and 10 show that for the Whittier soil the maximum percentage of moisture is not at the bottom of the soil column, but at an appreciable distance above it. These curves show the same general form as the previous ones. Referring to the table, it will be seen that the maximum percentage of moisture in tube No. 9 is found at the fourth inch, or at one-seventh of the height. In tube No. 10 the maximum percentage of moisture is found at the fifth inch, or at one-fourth of the height. It is worth noting that the maximum percentage of moisture in these two tubes was found at about the same height, although the one tube stood 11 days longer than the other, and the moisture in tube No. 9 ascended nearly 50 per cent farther than in tube No. 10.

The average percentage of moisture found in tube No. 9 at the end of the experiment was 44.67 per cent, and in tube No. 10 the average percentage was 43.44 per cent. This is a very close agreement for two tubes so differently treated. This agreement would indicate that any different general arrangement of the moisture distribution that might occur in these columns with time would be very gradual, if it occurred at all.

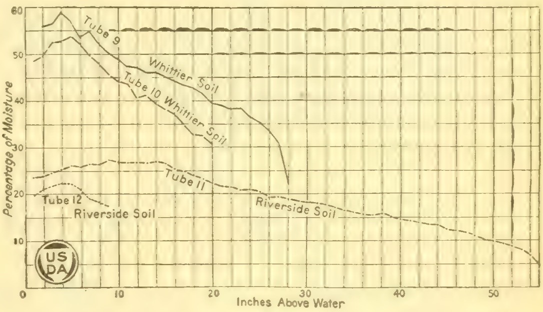

FIG. 4.—Distribution of moisture in vertical columns, Whittier and Riverside soils.

In tube No. 9 the average percentage of moisture is not found until about the sixteenth inch, or at a little less than two-thirds the height of the column. In tube No. 10 the average percentage is found at about the eleventh inch, or a little more than half the height.

The curves for the Riverside soil, tubes Nos. 11 and 12, show the same general moisture distribution as the preceding curves. The maximum percentage of moisture is found, not at the bottom inch, but at some distance above it.

The curve for tube No. 11 shows rather a uniform distribution of moisture and only small secondary peaks. Although tube No. 12 stood but a few minutes the maximum percentage of moisture is found above the third inch. The rather equal moisture distribution from the fourth to the sixteenth inch shown in tube No. 11 is noteworthy.

Referring to Table 5, it is found that in Tube No. 11, the maximum percentage of moisture is 27.36, while the percentage of moisture in the first inch is only 23.55. The average percentage of moisture in tube No. 11 is 18.87, which is not found until the twenty-ninth inch or half-way up the tube. There is found in the bottom half of the tube 65 per cent of all the moisture in the tube, and but 35 per cent in the upper half of the tube.

Tube No. 12 is inserted to show that the moisture distribution may follow the general rule, for tubes in water a few minutes only, as well as for those in water for a month or more.

SANTA CLARA AND CACHE VALLEY SOILS.

The fourth set of experiments consisted of three tubes filled with soil from Santa Clara County, Calif., and one tube filled with medium loam from Cache Valley, Utah. The Santa Clara soil is very similar in its capillary behavior to the Whittier soil. The Cache Valley soil is typical of the bench loam soils of the Intermountain States.

Tube No. 13 filled with Santa Clara soil was packed in 2-inch layers and made firm by raising from the floor and dropping in a manner similar to the packing of tube No. 1. After packing and before placing in position, the tube was inverted so that the end filled last was at the bottom when placed in water. This tube was allowed to stand 13 days and then was sampled immediately.

Tube No. 14, filled with Santa Clara soil, was packed by the same method as tube No. 13. The joints of the 1-inch sections were open and not sealed with friction tape. This tube stood in position 15 days and was then sampled immediately.

Tube No. 15 was filled with Santa Clara soil and packed in the same way as tubes Nos. 13 and 14. This tube was also inverted, allowed to stand in position 18 days and then sampled immediately.

Tube No. 16 was filled with Cache Valley soil packed in the same way as tube No. 14. This tube was allowed to stand in position 24 days, and was then sampled immediately.

Table 6, arranged in the same manner as the preceding tables, gives the moisture distribution at the end of the tests of the last four tubes.

TABLE 6.—*Distribution of capillary moisture in vertical soil columns of Santa Clara and Cache Valley soils, by percentage.*

Distance above water.	Tube No. 13.	Tube No. 14.	Tube No. 15.	Tube No. 16.	Distance above water.	Tube No. 13.	Tube No. 14.	Tube No. 15.	Tube No. 16.
Inches.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Inches.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	38.48	38.64	34.07	30.06	21	21.23	22.54	21.82	28.02
2	36.48	37.69	34.06	34.08	22	19.13	21.32	20.22	27.97
3	36.43	39.51	34.14	33.72	23	16.11	19.00	17.82	27.05
4	37.24	39.83	35.69	33.18	24		17.05	14.83	26.42
5	36.58	39.41	36.46	33.05	25		13.14		25.78
6	38.15	40.23	37.13	34.24	26				25.31
7	37.39	40.43	38.21	34.63	27				24.65
8	37.97	35.03	36.38	35.03	28				24.01
9	35.30	38.34	34.35	34.59	29				23.39
10	34.47	39.80	33.39	34.25	30				22.84
11	32.88	33.73	32.81	34.58	31				21.87
12	31.83	33.73	31.86	33.30	32				21.28
13	31.21	32.32	30.56	33.06	33				20.60
14	29.99	31.24	29.73	31.30	34				19.77
15	28.73	29.84	28.88	31.09	35				18.82
16	27.70	28.33	27.90	30.46	36				17.50
17	26.62	27.65	26.52	29.73	37				15.59
18	25.49	26.52	25.88	29.53	38				13.07
19	24.05	25.39	24.76	28.87					
20	23.11	23.94	23.04	28.56	Average	30.72	30.98	29.60	27.67

Figure 5 shows graphically the data of Table 6. It will be observed that in the curves for tubes Nos. 13 and 14 the percentage of moisture in the first, or bottom inch is greater than that in the second and third inches. To this extent they differ from most of the preceding figures. In both of these curves, after the third inch, there is an appreciable rise in moisture percentage followed by a considerable length of rather constant moisture content. From the eighth and the eleventh inches, respectively, there is a rather uniform rapid decline in the moisture content. The curve for tube No. 15 shows a distribution of moisture similar to that in the preceding tubes, excepting tubes Nos. 13 and 14. The reason for the differences in moisture distribution in tubes No. 13 and No. 15 is not apparent, unless it is the difference in the time these tubes stood in position before sampling.

Referring to Table 6, it is found that in tube No. 13 the maximum percentage of moisture was found in the bottom inch, with almost as much in the sixth inch. Between the first inch and the sixth inch there was less moisture than at either of those points. The average percentage of moisture in this tube was 30.72 per cent, and this percentage is found between the thirteenth and the fourteenth inches or more than halfway up the tube. The lower 11 inches of the tube have 57 per cent of all the moisture in the tube.

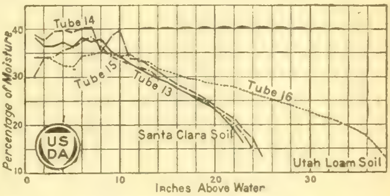

FIG. 5.—Distribution of moisture in vertical columns, Santa Clara and Utah loam soils.

In tube No. 14 the maximum moisture content, 40.43 per cent, was at the seventh inch. The average percentage of moisture was 30.98 per cent, and this percentage was found at about the fourteenth inch, or a little more than halfway up the tube. In the lower 12 inches of this tube there was 59 per cent of all the moisture in the tube.

In tube No. 15 the maximum moisture content, 38.21 per cent, was at the seventh inch, or about one-third the way up the tube, while in the first inch it was only 34.07 per cent. The average in this tube was 29.60 per cent of moisture. This percentage of moisture is found at the fourteenth inch, or at seven-twelfths of the height of the tube. The lower half of the tube contains 59 per cent of all the moisture in the tube. The bottom fourth of the tube contains an average of 35.26 per cent moisture, or only 0.76 per cent more than the average of the second fourth of the tube.

In tube No. 16, filled with the Cache Valley soil, a rather constant percentage of moisture was found in the lower third of the tube, except for the bottom inch. The maximum percentage of moisture is found at the eighth inch, or at about one-fifth the height of the column. It is noticed that if the first, or bottom inch, be eliminated, there is a decline in the moisture content from the bottom of the tube upward for a distance of 3 inches, then a rise in moisture for the next 3 inches. From the ninth to the eleventh inch, inclusive, the moisture content is approximately the same. From the eleventh inch to the top of the tube there is a gradual decrease in the moisture content. The Cache Valley soil, as represented by this tube, differs from the

others in the uniformity of the moisture content of the bottom third of the tube. The average moisture content of the whole tube is 27.67 per cent. This percentage of moisture is found at the twenty-second inch, or nearly six-tenths the height of the tube. The lower half of the tube contains 59 per cent of all the moisture in the tube. In the bottom nine inches of the tube the average moisture content is 33.62 per cent; in the next 9 inches the average moisture content is 31.92 per cent; in the next 10 inches 26.66 per cent; and in the last 10 inches, 19.47 per cent. The rapid decline in moisture content is found in the top fourth, as shown by the curve, Figure 5.

DISTRIBUTION OF MOISTURE IN HORIZONTAL SOIL COLUMNS.

While these tubes are designated as "horizontal," they all had a rise of one-tenth of an inch per foot from the water end to the outer end.

Although the tests made with the horizontal tubes do not give sufficient data upon which to base any very definite conclusions, four of them are included to indicate what distribution of moisture may be expected in soil columns handled as these were handled.

The four tubes in this set were each manipulated in a different way. Differing as they do these four tubes were selected for the reason that there were not sufficient tests made by any one method to give more conclusive data than could be obtained from a single test.

It must be kept in mind that all horizontal columns had a vertical rise of 4 inches from the water in the tank before a change to the horizontal was made. The arbitrary distance was used so that the results might be adapted to the work done previously at Riverside.

In sampling the tubes, the 4 vertical inches and the first horizontal inch of the tube was discarded. Thus, the first sample, designated as the first inch in the table, was the sixth inch from the water.

Tube No. 17 was filled with Idaho lava ash soil and was packed in the same way as tube No. 1. This tube stood 21 days and was then sampled immediately.

Tube No. 18 was filled with Riverside decomposed granite soil and was packed in the same way as tube No. 1. In this tube the moisture had reached the outer end of the soil in the tube a few days before samples were taken. For a few days evaporation was taking place at the outer end of the soil column and in that respect this tube differed from all the others. This tube stood 32 days before sampling.

Tube No. 19 was filled with soil from Cache Valley and was packed in the same way as tube No. 1. The horizontal joints of this tube were not wrapped with friction tape and were open to air circulation. To that extent this tube differed from all the others. It stood 26 days before sampling.

Tube No. 20 was filled with soil from Santa Clara Valley and was packed in the same way as tube No. 1. This tube stood 21 days before sampling.

Table 7 gives the percentages of moisture as determined in the four tubes.

TABLE 7.—*Distribution of capillary moisture in horizontal soil columns of California, Utah, and Idaho soils, by percentages.*

Distance from water.	Tube No. 17.	Tube No. 18.	Tube No. 19.	Tube No. 20.	Distance from water.	Tube No. 17.	Tube No. 18.	Tube No. 19.	Tube No. 20.
Inches.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Inches.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	31.68	25.75	33.66	32.20	43	29.08	27.40		
2	32.74	25.73	33.59	31.62	44	28.90	26.82		
3	31.63	25.98	34.29	33.14	45	28.69	26.27		
4	33.56	25.57	34.04	32.36	46	28.79	26.74		
5	33.04	26.00	34.25	31.82	47	28.51	26.85		
6	32.54	25.65	33.25	31.11	48	28.14	26.00		
7	32.20	26.67	33.09	31.88	49	28.16	25.27		
8	32.98	26.69	32.88	29.11	50	27.87	26.67		
9	34.23	27.67	32.35	27.89	51	27.26	26.55		
10	33.39	26.35	31.96	26.42	52	27.06	25.49		
11	33.86	27.09	31.23	25.50	53	27.32	27.18		
12	33.77	28.09	31.06	23.89	54	27.12	27.45		
13	33.27	26.96	30.77	22.50	55	26.47	27.24		
14	33.65	26.61	30.07	21.24	56	26.18	26.59		
15	33.46	26.47	29.71	19.40	57	26.10	26.11		
16	33.39	26.43	29.25	16.75	58	25.90	26.89		
17	33.27	27.36	28.96		59	25.40	25.56		
18	33.17	26.80	28.27		60	25.26	26.58		
19	32.55	26.39	28.21		61	25.18	27.21		
20	32.74	27.03	26.96		62	24.97	26.88		
21	32.78	26.39	26.36		63	24.91	25.95		
22	32.63	26.61	26.12		64	24.36	27.02		
23	32.15	25.78	25.66		65	22.78	26.54		
24	32.15	25.48	24.96		66	22.91	26.57		
25	31.81	25.26	23.44		67	22.39	25.73		
26	31.35	26.84	22.69		68	21.83	25.67		
27	31.67	26.00	22.00		69	21.83	26.65		
28	31.28	26.14	21.22		70	20.88	26.47		
29	31.09	27.18	20.24		71	20.19	26.60		
30	31.46	26.18	18.82		72	18.91	26.87		
31	31.51	27.25	16.75		73	18.05	26.34		
32	31.60	28.22			74	16.22	25.98		
33	31.14	27.69			75	13.25	27.00		
34	30.25	26.20			76		26.39		
35	30.54	27.48			77		26.85		
36	30.58	26.47			78		27.10		
37	30.24	25.61			79		26.39		
38	29.99	27.80			80		26.59		
39	30.11	27.69			81		27.12		
40	29.61	26.43							
41	28.91	25.52			Average.	28.71	26.58	28.26	27.30
42	[1] 29.00	27.30							

[1] Interpolated.

Figure 6 gives in diagrammatic form the information contained in Table 7. A glance at the figure indicates a much more uniform moisture distribution in the horizontal columns than in the vertical columns. While it appears in the figure that the maximum percentage of moisture is not found exactly at the water end of the tube, yet the

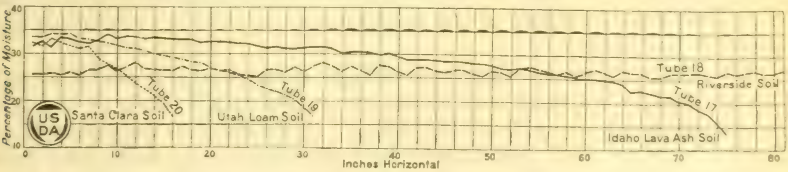

FIG. 6.—Distribution of moisture in horizontal columns.

maximum percentage of moisture found in the tube is not much greater than the percentage found in the first inch. The apex in the horizontal tubes is not so pronounced as in the vertical tubes. The striking feature of the curves is the relatively long stretch of the column containing approximately the same percentage of moisture.

It will be noticed that in tube No. 18, filled with the Riverside soil, the moisture content at the extreme right end is greater than at the

left end of the line. It will also be noticed that no decrease in the moisture content is indicated toward the extreme end of the line. In explanation of this condition it must be kept in mind that the moisture had reached the end of the soil column several days before sampling. This condition was not present in the other columns.

The curve for tube No. 18 is much more regular than those of tubes Nos. 17 or 20, and this may be accounted for by the open-jointed tube.

Referring to Table 7, it is found that the average percentage of moisture in tube No. 17 is 28.71 per cent, and that this percentage of moisture was found between the forty-sixth and forty-seventh inches, or not quite two-thirds the horizontal length of the tube. It is found that the greatest percentage of moisture is at the ninth inch, or about one-eighth the horizontal length. The moisture content of the last inch is about 40 per cent of that of the first inch. Dividing the tube into four parts, and commencing with the part nearest the tank of of water, the average moisture content is 33.07 per cent, in the first 19 inches, 31.42 per cent in the next 19 inches, 28.07 per cent in the next 19 inches, and 21.96 per cent in the last 18 inches. The third quarter of the tube contains about the same average percentage of moisture as the whole tube. The first half of the tube contains about 56 per cent of all the moisture in the tube. This tube, like the vertical tubes, shows the most rapid decrease in moisture percentage, inch by inch, in the fourth quarter.

The average percentage of moisture found in tube No. 18 was 26.58 per cent. This percentage is slightly more than that found at the first inch, and slightly less than that found at the last inch. In the upper 41 inches of the tube there is a trifle more moisture than in the lower 40 inches. Dividing this tube into four parts as in the case of the previous tube, the average percentage of moisture in the first 20 inches was 26.56 per cent; in the next 20 inches, 26.63 per cent; in the third 20 inches, 26.52 per cent; and in the last 21 inches, 26.57 per cent. The most that can be said of this tube is to call attention to the surprising uniformity of the moisture content throughout the tube.

The average percentage of moisture found in tube No. 19 was 28.26 per cent, and this percentage is found at the eighteenth inch, or a little more than half the length of the tube. The average percentage of moisture found in the first 8 inches was 33.63 per cent; in the next 8 inches, 30.80 per cent; in the third 8 inches, 26.94 per cent; and in the last 7 inches, 20.74 per cent. These averages indicate a rather uniform decrease in the moisture content with distance from the water. The first 15 inches of the tube contained 55 per cent of all the moisture in the tube.

In tube No. 20 the average percentage of moisture was 27.30 per cent, and this percentage was found near the ninth inch, or a little more than half the length of the tube. The average percentage of moisture found in each fourth of the tube, beginning with the first fourth, was 32.33, 30.98, 25.92, and 19.97 per cent, respectively. Fifty-eight per cent of all the moisture in the tube was found in the first half.

These four tubes, with the exception of tube No. 18, indicate about the same distribution of moisture. It is very evident that in tube No. 18 the fact that the moisture had reached the end of the soil column before samples were taken influenced the moisture distribution.

DISTRIBUTION OF MOISTURE IN TUBES INCLINED DOWNWARD.

Several tests were made to determine the distribution of moisture in soil columns inclined downward from the horizontal. In all such tests the part of the soil column that was in the water extended vertically upward various distances above the water surface before a change in direction was made in the soil column. This vertical upward extent of the soil column to where a change was made to the downward direction is termed the "lift." This "lift" is the same, except as to length, as in the horizontal columns.

Tube No. 21 filled with the Idaho sandy soil had a "lift" of 4 inches and was then inclined downward at an angle of 30 degrees from the horizontal. The inclined part of the tube was 5 feet in length. The lower end of the inclined part was covered with cheese cloth to hold the soil in the tube. This column was sampled after water commenced dripping from the lower end of the inclined part.

Tube No. 22 was filled with Riverside decomposed granite soil. The "lift" was 9 inches; there was then a horizontal length of 3 inches and then a vertically downward length of 84 inches. The column was sampled before the moisture had reached the lower end of the tube.

Tube No. 23 was filled with Santa Clara soil and had a vertical "lift" of 4 inches. From this height the tube was inclined downward 30 degrees from the horizontal and was similar to tube No. 21. The tube was sampled before water dripped from the lower end of the inclined part of the tube.

Table 8 and Figure 7 give the distribution of moisture in these three columns.

TABLE 8.—*Distribution of capillary moisture in tubes inclined downward from the horizontal.*

Distance from apex.	Tube No. 21.	Tube No. 22.	Tube No. 23.	Distance from apex.	Tube No. 21.	Tube No. 22.	Tube No. 23.
Inches.	*Per cent.*	*Per cent.*	*Per cent.*	*Inches.*	*Per cent.*	*Per cent.*	*Per cent.*
1	13.65	17.55	35.95	32	14.78		
2	13.33	18.76	36.11	33	14.97		
3	13.64	18.53	36.34	34	14.80		
4	14.20	17.97	35.49	35	14.97		
5	14.47	18.12	35.41	36	15.33		
6	14.81	17.48	34.60	37	15.30		
7	12.78	17.52	34.48	38	15.41		
8	13.91	17.67	34.31	39	14.31		
9	13.18	16.61	34.05	40	15.02		
10	15.15	16.49	34.43	41	15.67		
11	13.15	16.85	34.21	42	16.08		
12	14.06	16.49	34.35	43	15.49		
13	14.84	16.34	33.74	44	15.95		
14	14.29	16.15	33.38	45	16.19		
15	13.77	15.89	32.30	46	16.72		
16	14.36	15.57	32.32	47	16.62		
17	15.63	15.76	30.97	48	16.99		
18	13.08	15.60	31.00	49	17.39		
19	14.14	15.29	30.56	50	18.16		
20	15.14	14.78	29.30	51	17.74		
21	14.45	14.99	29.06	52	18.06		
22	13.96	14.77	28.70	53	19.23		
23	14.84	14.26	28.02	54	19.25		
24	13.81	14.17	27.20	55	20.03		
25	14.23	13.60	26.36	56	20.80		
26	14.38	13.18	24.80	57	21.06		
27	14.05	12.78	23.80	58	20.66		
28	14.11	12.19	21.80				
29	15.13	11.15	18.18	Average	15.46	15.53	31.07
30	14.70	9.33					
31	14.74			X[1]	22.41	28.62	41.40

[1]Sample "X" is soil from the "wick" and 2 inches below the apex of the vertical part of the tube.

While but 3 tubes inclined downward from the horizontal are included, some 24 tubes were used. To have included more would have added materially to the length of this report without adding correspondingly to its value, since information secured from the other tubes is similar to that presented above and differs only in degree or as influenced by methods.

In considering tubes Nos. 21, 22, and 23, it must be kept in mind that in tube No. 21 the moisture had reached the lower end of the inclined column and that water was dripping from the lower end when the samples were taken. In the other two tubes the moisture had not reached the lower end of the columns, and there was dry soil below and in contact with the lower extremity of the wet soil. In these last two tubes two forces tended to draw the moisture downward in the inclined part of the tube at the time the samples were taken, a capillary force and the force of gravity, while in tube No. 21 there was only the force of gravity acting at the lower end of the soil column.

Referring to Table 8 and Figure 7, it is found that in tube No. 21

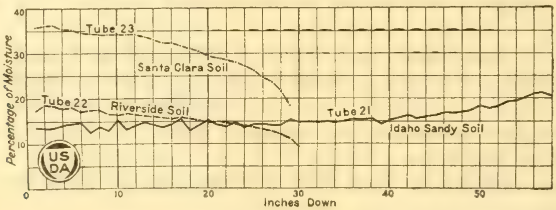

FIG. 7.—Distribution of moisture in columns inclined downward.

there is a very uniform percentage of moisture from the upper end of the inclined part of the soil column to within about 15 inches of the lower end of the soil column. From the fortieth to the fifty-eighth inch there is an increase in the moisture percentage and the greatest percentage of moisture in the entire soil column is nearly at the lower end of the inclined part of the column. The distribution of moisture in the 15 inches of the column nearest the apex is somewhat similar to that found in the vertical soil columns. At the lower end the absence of any capillary action below the wetted area causes a piling up of the moisture. The uniform distribution of moisture by percentage in the first 40 inches of the inclined soil column is significant in considering the distribution of moisture in the field under irrigation, as it would indicate that there is a maximum or optimum percentage of moisture that can be retained within the soil and that this optimum is not comparable to capillary saturation or many of the other terms of measure now in use by the soil physicists.

In tubes Nos. 22 and 23 the samples were taken while the moisture was still moving downward within the soil column, showing a distribution of moisture differing materially from that shown in tube No. 21. In these tubes the maximum percentage of moisture is near the upper end of the column and the minimum moisture content at the lower end. The decrease in the percentage of moisture from the top to near the bottom of the column is rather uniform for both these soils. This distribution of moisture would be somewhat comparable to the distribution found in a field under irrigation where

the soil is deep. Hilgard in "Soils" (1916), and Widsoe and McLaughlin in Bulletin 115 of the Utah Experiment Station report finding under field conditions a distribution of moisture somewhat similar to the distribution shown in the last two tubes.

In considering tubes Nos. 22 and 23 it must be kept in mind that in tube No. 22 the "lift" was 9 inches, while in tube No. 23 it was but 4 inches. In the former tube the moisture was furnished in comparatively meager quantities to the upper end of the inclined part of the soil column and in tube No. 23 rather copiously The former tube contained comparatively light pervious soil. The distribution of moisture in these two tubes was quite similar.

Sample X (see Table 8) shows the percentage of moisture found in that part of the soil column contained in the "lift," which is between the surface of the water in the tank and the point where the soil column changes direction. This sample in all cases was taken 2 inches below the apex of the tube. It is significant that the inclined part of the column can dispose of more moisture than can be furnished by the vertical part of the tube. That gravity in conjunction with capillarity would cause such a difference in moisture distribution within 2 or 3 inches is somewhat surprising. Had samples been taken on each side of the apex of the tubes and nearer to the apex there is no doubt that this same difference in moisture would have been shown within a much shorter distance.

SUMMARY.

The moisture, as found in these experiments, was not distributed at a uniformly decreasing rate with height above the water.

The maximum percentage of moisture was found, not immediately above the water surface, but at an appreciable distance above it.

The line plotted to represent the percentage of moisture found in the column is an irregular curve, with the end representing the upper end of the column approaching a straight line. In some of the experiments the second fourth of the column, from the bottom, contained as much or nearly as much moisture as the bottom fourth of the column.

In all tests except those in which Idaho sandy soil was used, extending over a period of 10 days or longer, the lower half of the tube contained at all points more moisture than the average amount contained throughout the column.

The point at which the average percentage of moisture was found varied from the middle to two-thirds the height of the column.

The height at which the maximum percentage of moisture was found varied from one-seventh to one-fourth the height of the moist part of the soil column.

In all columns there was a considerable length, a few inches above the water, containing approximately the same percentage of moisture.

The various methods of packing the soil columns tried in these experiments did not appear to alter the general plan of moisture distribution.

The facility with which air may escape from or enter into the soil column does not alter the general plan of the moisture distribution.

The ventilated soil columns had a slightly more uniformly varying moisture content with height above water than the columns not ventilated.

From these tests it is safe to say that the general moisture distribution found prevailed in the soil columns of small area used by other investigators in their experimental work.

In horizontal soil columns of small area and having a vertical rise of 4 inches before a change to the horizontal the four tests given show that—

The maximum percentage of moisture occurs close to but not necessarily at the end of the tube nearest the water;

The average percentage of moisture in the tube was found at a distance from the water equal to more than half the length of the tube;

The distribution of moisture is altered when the moisture reaches the outer end of the tube.

In tubes inclined downward from the horizontal—

The greatest percentage of moisture is found at the top of the tube when gravity and capillarity are both acting;

The total quantity of water which can be retained by the soil column by capillarity in the absence of ground water is much less than capillary saturation.

If the downward movement of capillary moisture be checked by an impervious stratum, the distribution of moisture above this stratum will in time be similar to the distribution of moisture in a vertical soil column extending upward from this stratum and with a water table at the stratum.

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE.

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